UNSTEADY AERODYNAMIC WAKE OF HELICOPTER MAIN-ROTOR-HUB ASSEMBLY

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
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To my beloved parents (Haji Ishak and Hajah Aminah), wife (Norhayati) and children (Izzati, Imran and Ikhmal)

ABSTRACT

The helicopter tail shake phenomenon is an area of great concern to helicopter manufacturers as it adversely affects the overall performance and handling qualities of the helicopter, and the comfort of its occupants. This study is intended to improve the understanding of the unsteady aerodynamic load characteristics triggered by the helicopter main-rotor-hub assembly wake that lead to this phenomenon by experimental and numerical investigations. In this research work, a simplified NASA standard fuselage model was mated to a main-rotor-hub assembly from a remote-control helicopter. Data of pressures and velocities inside the wake, as well as the aerodynamic drag, corresponding to the variations of helicopter's advance ratios and pylon configurations were captured. This work had gained some useful information towards further understanding of this long running issue, with a potential to minimise the problem. The dynamic analysis, through the power spectral density, root-mean-square and probability density function analyses, was also conducted and had successfully quantified the frequency and unsteadiness of main-rotor-hub assembly wake. Computational Fluid Dynamics (CFD) had also been carried out to model and simulate the wake dynamics, and were successfully validated using experimental results. The Sliding Mesh method was opted to simulate the rotation of main-rotor-hub assembly whilst the aerodynamic flow field was computed using the Large Eddy Simulation equations. As the CFD results were found to be in accordance with the experimental results, a reliable CFD modelling technique for the unsteady wake analysis of the helicopter main-rotor-hub assembly wake has thus been forwarded. Accordingly, this numerical modelling could be used to supplement experimental work. In addition, this research programme had also successfully proposed a modelling technique of simplified helicopter main-rotor-hub assembly viable for unsteady aerodynamic wake studies.

ABSTRAK

Fenomena getaran pada ekor helikopter merupakan suatu isu yang dipandang berat oleh para pengeluar helikopter kerana ia memberi kesan kepada prestasi keseluruhan dan kualiti kawalan helikopter, serta keselesaan penumpang. Kajian ini bertujuan untuk menambahkan lagi kefahaman ke atas ciri keracak aerodinamik tidak-tetap dari hab-rotor-utama helikopter yang merupakan sumber utama penyebab fenomena ini, melalui kerja-kerja penyelidikan secara ujikaji dan simulasi berkomputer. Model fiuslaj piawai NASA yang dipermudah digandingkan bersama hab-rotor-utama dari helikopter kawalan jauh untuk digunakan sebagai model kajian. Data tekanan dan halaju dalam keracak, serta daya seret aerodinamik pada pelbagai nilai nisbah-maju dan konfigurasi pelindung hab-rotor-utama helikopter, telah diperolehi. Kajian yang dijalankan ini telah berjaya memberikan beberapa maklumat berguna yang mungkin berpotensi untuk mengurangkan permasalahan yang telah berlanjutan sekian lama ini. Analisis dinamik, menerusi analisis terhadap ketumpatan spektra kuasa, punca min kuasa dua dan fungsi ketumpatan kebarangkalian, juga dilakukan dan berjaya mengenalpasti frekuensi serta ketidak-tetapan aliran keracak hab-rotor-utama helikopter. Simulasi dinamik bendalir berkomputer juga dilakukan untuk memodelkan dan mensimulasikan dinamik keracak dan telah berjaya di tentu-sahkan dengan keputusan ujikaji. Kaedah Jejaring Gelangsar diaplikasikan untuk mensimulasikan putaran hab-rotor-utama helikopter manakala medan aliran aerodinamik dikira menggunakan persamaan Simulasi Olakan Besar. Oleh kerana hasil simulasi ini sejajar dengan keputusan ujikaji, suatu teknik permodelan simulasi untuk analisis keracak tidak-tetap hab-rotor-utama helikopter telah berjaya dihasilkan. Justeru itu, simulasi berkomputer ini juga boleh digunakan untuk melengkapkan lagi kerja ujikaji. Di samping itu, penyelidikan ini juga telah berjaya mencadangkan satu model bagi hab-rotor-utama helikopter dipermudah yang boleh digunakan bagi kajian keracak aerodinamik tidak-tetap.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C_D	-	Aerodynamic drag coefficient
C_n	-	Yawing moment coefficient
Cp_o	-	Total pressure coefficient
$Cp_{o\ mean}$	-	Mean total pressure coefficient
N	-	Number of data
P_∞	-	Free stream static pressure (Pa)
Po	-	Total pressure (Pa)
q_∞	-	Free stream dynamic pressure (Pa)
R	-	Main rotor blade radius (m)
V_∞	-	Free stream or flight velocity (m/s)
β	-	Sideslip angle (deg)
Ω	-	Rotor rotation speed (radian/s)
μ	-	Helicopter rotor advance ratio
α	-	Angle of attack (deg)
γ	-	Incidence angle (deg)
ψ	-	Yaw angle (deg)

Abbreviations

CFD	-	Computational Fluid Dynamics
DNW-LST	-	German-Dutch Low Speed Tunnel
I/A	-	Interactional Aerodynamics
LabView	-	Laboratory Virtual Instrumentation Engineering Workbench
LES	-	Large Eddy Simulation
LDV	-	Laser Doppler Velocimetry
MRF	-	Multiple Reference Frames
NLR	-	National Aerospace Laboratory

NOTAR	-	No Tail Rotor
PSD	-	Power Spectral Density
PDF	-	Probability Density Function
RANS	-	Reynolds Averaged Navier-Stokes
RC	-	Remote Control
RMS	-	Root-Mean-Square
ROBIN	-	Rotor Body Interaction
UTM	-	Universiti Teknologi Malaysia

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview of Helicopter Tail Shake Phenomenon

A helicopter is an aircraft that is lifted and propelled by one, or even more horizontal rotors, as is the case with the Boeing CH-47 Chinook, where each rotor consisting of two or more rotor blades.

The **I**nteractional **A**erodynamic (I/A) problems remain a long dragged issue in spite of numerous endeavours by a lot of companies (Waard and Trouvé, 1999). The statement is considerably supported by Hassan *et. al* (1999) which state the flow fields that govern the aircraft's handling qualities and responsiveness have often baffled designers. One of the critical I/A problems is the helicopter tail shake phenomenon that adversely affected the overall performance, occupant comfort and handling qualities of helicopter (Roesch and Dequin, 1983; Waard and Trouvé, 1999). According to Coton (2007), this phenomenon is a very complex problem and the European Helicopter Project (GO AHEAD) and French-Germany Project (SHANEL) are currently believed to look seriously at this phenomenon.

Essentially, the phenomenon occurs as a consequence of interaction between the unsteady main-rotor-hub assembly wake and the vertical tail of the helicopter (Coton, 2009), as be illustrated in Figure 1.1.

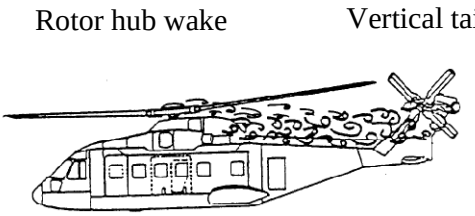

Figure 1.1: Schematic of tail shake phenomenon (Waard and Trouvé, 1999)

In fact, the phenomenon is a dynamic response of the structure to the main-rotor-hub assembly wake (Eurocopter, 2006). According to Roesch and Dequin (1983), with more new faster helicopter be developed and raise in mission requirements (Hassan *et al*., 1999), the problems arising from the main-rotor-hub assembly's wake interactions with the tail surfaces have become more critical in such:

(i) Additional drag and reduced performance due to the low energy wake triggered by the main-rotor-hub assembly's wake.

(ii) Penalties to vehicle stability characteristics in pitch and yaw occur when the horizontal tail, vertical tail or tail rotor are surrounded by the highly unsteady wake. The effectiveness of stabilizer as well be degraded due to the dynamic pressure loss inside the wake.

(iii) Unsteady flow components in the turbulent wake may cause structural buffeting of the tail surfaces. According to Waard and Trouvé (1999), these vibrations will be transmitted to cockpit and may deteriorate occupant comfort, as well adversely affect crew efficiency. Figure 1.2 illustrates the comfortless of the crew during tail shake phenomenon. Worked by Hassan *et al*. (1999) had also shared the same findings.

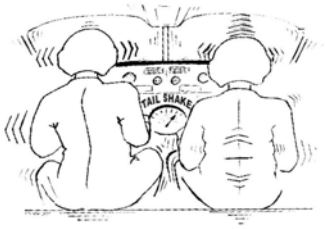

Figure 1.2: Vibrations in the cockpit (Waard and Trouvé, 1999)

(iv) In the case of the frequency of main-rotor-hub assembly's wake coincides with a natural frequency of the tail parts, strong amplification of the vibration would occur. Consequently, premature structural failure may happen due to fatigue problem.

With these mentioned penalties, apparently extensive researches are much required to be done in this field in the hope to minimize the problems.

1.2 The Needs of Vertical Tail

Theoretically, the instant solution to this tail shake problem is to design a helicopter without the vertical tail. However, the vertical tail is required for two distinct purposes:

(i) To house or mount the tail rotor - with a single main rotor helicopter, the creation of torque as the engine turns the rotor blades create a torque effect (Padfield, 1996) that causes the body of the helicopter to turn in the opposite direction of the rotor blades. Therefore, tail rotor is needed to produce yaw moment to compensate main rotor torque as be illustrated in Figure 1.3.

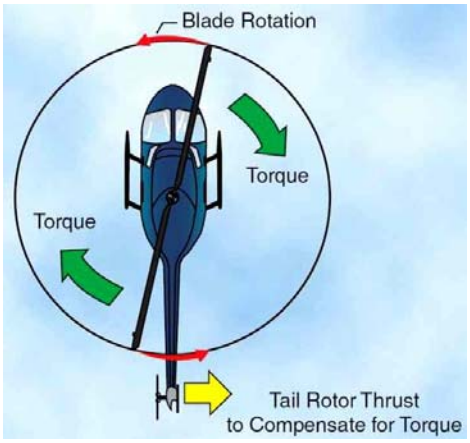

Figure 1.3: Torque effect on a helicopter (Google Images, 2011)

(ii) For directional stability - in order to be statically stable in directional mode, the yawing moment derivative, Cn_{β} must be a positive value (Nelson, 1998).

Efforts had been made to replace tail rotor with different mechanisms that serve the same purpose. One of them is the NOTAR helicopter, an acronym for **NO TA**il **R**otor as shown in Figure 1.4, which is a relatively new helicopter anti-torque system that eliminates the use of the tail rotor on a helicopter. It uses jet thrusters to produce side force, and thus yaw moment to counter act the main motor torque.

Figure 1.4: MD Helicopters 520N NOTAR (Wikipedia, 2011)

Nevertheless, NOTAR helicopters still need to have vertical tail for its directional stability; consequently it is still being exposed to tail shake phenomenon. Works done by Ishak *et. al* (2008) on a generic 14% scaled-down model of Eurocopter 350Z helicopter had shown without the vertical tail, the helicopter would not be statically stable in directional mode as the yawing moment derivative, Cn_{β} becoming a negative value, as be demonstrated in Figure 1.5. It shows with the negative value of Cn_{β}, the helicopter deviates more from its initial equilibrium position. For the note, Cn is taken positive in clockwise direction looking from the top.

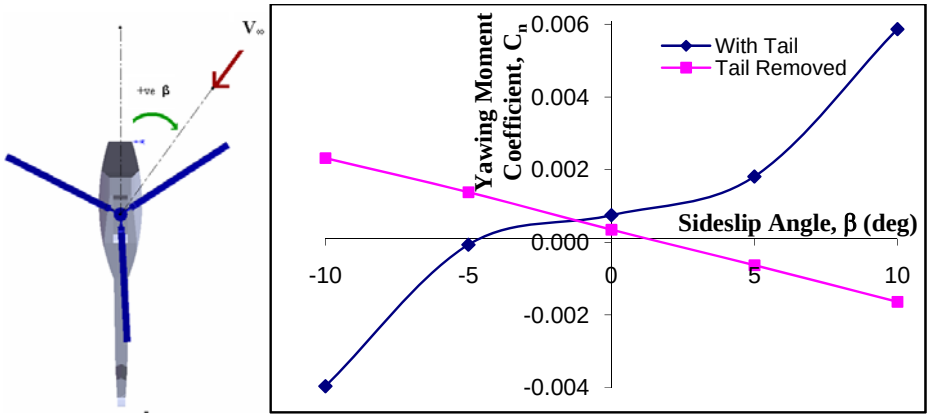

Figure 1.5: Helicopter Directional Stability (Ishak *et. al*, 2008)

This leads development of a helicopter which has neither vertical tail, nor tail rotor. It uses air-jet, positioned at the end of tail boom, for anti-torque and directional stability – this is made possible by adjusting the speed and amount of air jet in response of disturbance. However this kind of helicopter becomes very expensive and totally dependent on complex electronic control system, which its reliability could be an issue to some people.

For these highlighted reasons, new helicopter design still needs to be equipped with vertical tail assembly and thus, tail shake phenomenon issue is still relevant and needs to be addressed appropriately.

1.3 Review of Previous Related Tests

Previous researches such as Moedersheim and Leishman (1995) had done some total pressure measurements on the rotor wake but the advance ratios of the works were very low, which were only up to 0.3. Consequently the wake did not impinge on the empennage region. According to Sheridan (1979) and Ghee and Elliott (1995), the rotor hub wake can have a considerable influence on the flow environment in the vicinity of tail parts at high advance ratios. Therefore it is a need to do the investigations at higher advance ratios beyond 0.3, and this research aims to fulfil it.

Very little information on tail shake is available in the open literature because such information is commercially sensitive to manufacturers (Coton, 2009; Roesch and Dequin, 1983). There are only a few public papers on this subject and to make worst, some specific data and results are omitted to avoid being used by others. Hence, the information of these papers is not completed and could not straightly be used. As for instance, the chapter of tail shake test in Documentation Training (2006) provided by Eurocopter France to UTM-Aerolab is not furnished with the details of test configurations and data analysis - believed to be due to the confidential issues. Therefore it is hope that the open literature of this work can contribute literatures and thus benefit the rotorcraft community.

1.4 Research Key Area

As stated by Eurocopter (2007), the helicopter tail shake phenomenon is still not fully understood, justifying more researches to resolve this phenomenon. This work has shown merit as it manages to attract the Eurocopter France to assign one of its aerodynamicists to advice during the preliminary stage of the research.

Waard and Trouvé (1999) explain the helicopter tail shake phenomenon is being an interaction between the *aerodynamic excitation*, which is related to flight parameters, and the *structural response*, which is related to structure characteristics. As the aerodynamic excitation and structural response are two broadly diverse areas which are quite implausible to be covered in one merely PhD research, this study focused only on the aerodynamic excitation issue, in which works concentration will be on the hub wakes as it is believed to be the major contributor of the tail shake phenomenon (Cassier *et al.*, 1994; Hermans *et al.*, 1997; Eurocopter, 2007). Figure 1.6 illustrates the schematic diagram of the main-rotor-hub assembly where the hub wake is originated.

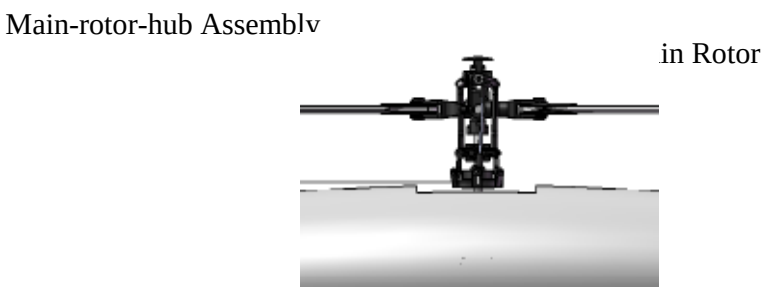

Figure 1.6: Helicopter main-rotor-hub assembly (inside the dotted-box)

The core analysis of this research work is to quantify the unsteadiness of helicopter's main-rotor-hub assembly wake with regards to the changes of flight parameters (i.e. the forward flight speed and main rotor rpm) and pylon configurations.

1.5 Problem Statement

Tail shake is very complex problem (Coton, 2007). It is one of the **I**nteractional **A**erodynamics (I/A) problems and remains, despite a considerable effort by different companies over the last two decades**,** difficult to predict with confidence before the first flight of a new helicopter (Waard and Trouvé, 1999). According to Eurocopter (2007), the helicopter tail shake phenomenon is an interesting problem to helicopters manufacturer but yet a very difficult subject to be understood.

As the helicopter main-rotor-hub assembly's wakes is believed to be the major contributor of the tail shake phenomenon (Cassier *et al*., 1994; Hermans *et al*., 1997; Eurocopter, 2007), this project will concentrate on the research of the unsteady aerodynamic characters triggered by helicopter’s main-rotor-hub assembly wake. Moedersheim and Leishman (1995) had done some total pressure measurements on the rotor wake but the advance ratios of the works were only up to 0.3, which is too low for the hub wake to influence the flow environment in the vicinity of tail parts. Consequently it is a demand to do the investigations at higher advance ratios beyond

0.3, and this research aims to cater the demand and thus giving additional information and contribution.

1.6 Objective of the Research Program

The objective of this study is to improve the understanding of the unsteady aerodynamic loads characters triggered by the wake of the helicopter's main-rotor-hub assembly that lead to the helicopter tail shake phenomenon by proposing experimental and numerical investigations to gain useful information which has the potential to minimize the long dragged helicopter's tail shake problem.

1.7 Scope of Work

This study concentrates on the aerodynamic loads fluctuation of the unsteady main-rotor-hub assembly wake that leads to helicopter tail shake phenomenon.

The project needs to design and fabricate the appropriate experimental set-up, do the **C**omputational **F**luid **D**ynamic (CFD) modelling and simulation, develop the test procedure, instrumentations and data analysis that should be able to predict the unsteady aerodynamic loads fluctuation elicited by helicopter's main-rotor-hub assembly wake.

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